MODERNIZATION OF MECHANICAL AND ELECTRICAL SYSTEMS AT NASHVILLE DISTRICT NAVIGATION LOCKS

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INTRODUCTION

The Nashville District Corps of Engineers operates and maintains 18 locks on the Tennessee and Cumberland Rivers. These complex, high-lift locks range in age from 10 to over 60 years old. As mechanical and electrical systems age, systems and components can become obsolete and unreliable. If not addressed, likelihood of breakdown and resulting delays to navigation could increase.

To prevent such delays, the Nashville District has pursued an aggressive, systematic program of modernizing the mechanical and electrical systems at these locks. In this regard, these modernization efforts have emphasized identifying and applying the latest advances in industrial, mechanical, and electrical equipment and controls technology, not just replacing in kind.

In addition, the Nashville District has had only one lock operator per shift since the 1960's. As navigation traffic has increased at most projects and more information management has been required of the operator, Nashville has strived to modernize and automate mechanical and electrical systems to make lock operations more efficient and safer and prevent the workload from requiring more than one operator per shift.

This paper details the evolution of mechanical systems and electrical controls technology at two of the District's navigation locks, Barkley Lock on the Cumberland River near Grand Rivers, Kentucky and Wheeler Auxiliary Lock on the Tennessee River near Rogersville, Alabama.

UPGRADES AND MODERNIZATION OF MECHANICAL AND ELECTRICAL SYSTEMS AT WHEELER AUXILIARY LOCK

HISTORY

The newly established Tennessee Valley Authority constructed Wheeler Auxiliary Lock on the Tennessee River near Rogersville, Alabama in the 1930=s. The 60-foot by 400-foot lock was originally equipped with electric-motor driven, open gear-reduction, sector-gear-type operating machinery for the miter gates and culvert valves. The lock operator=s benchboard controls utilized a conventional 240 vac hardwired relay based system.

UPGRADE OF ELECTRICAL CONTROL SYSTEM

In the early eighties, as part of a systematic upgrade of lock control systems in the Nashville District, Operations engineers initiated design studies for upgrading the Wheeler Auxiliary Lock electrical system. Control system upgrades at other district locks to date had been accomplished using standard hardwired relay-based technology. However, technical discussions with industrial control vendors indicated programmable logic control (PLC) system technology should be considered. Based on this, Nashville began reviewing and comparing to standard control technology, the PLC control systems offered by various manufacturers. This study of PLC based systems indicated several advantages over conventional relay systems for use in lock control leading to the decision to proceed with a PLC-based design. The PLC equipment was procured by supply contract and installed by government hired labor. The PLC equipment used was the Square D Company=s SYMAX remote I/O system with a Model 500 processor. Advantages of the PLC system are as follows:

Initial Design

PLC based design allows the design engineer flexibility in the initial design of sophisticated control circuitry with minimal change in hardware requirements. If desired, alternative control circuit operations can be simulated to determine the optimum system configuration. PLC based design provides for integration of a large number of different mechanical and electrical systems under a comprehensive control system. For example, an integral water level monitoring and control system for minimizing lock chamber overfilling and overemptying can be achieved with minimal hardwiring, the desired features being accomplished in the PLC=s ladder logic software programming.

Initial Installation Costs

The programmable controller system can result in substantial cost savings due to reduced hardware requirements. Very few hardwired relays are required. Properly laid out, the PLC remote I/O system can result in significant cost savings from reduction of required control cable.

Initial Control System Start-up and Functional Operational Testing

During initial start-up, the PLC=s built-in self-diagnostics and ability to monitor visually pushbutton and limit switch input status and control output logic status on-line is very beneficial. Perhaps an even greater advantage is the ability to easily make changes to control system logic as necessary to address latent and varying conditions enviably encountered in all projects.

Long-term Operation and Maintenance

The flexibility of revising control functions and real-time monitoring of lock control status, and the ease of expansion of the PLC control system when needed to meet future requirements are major benefits. The ease of maintenance offered by self-diagnostics and modular, plug-in design and the overall reliability of solid-state equipment would be impossible to achieve in a conventional control system.

FY 96 MITER GATE MACHINERY REPLACEMENT

General

By the early 1990=s, the original 1930's open-gear-reduction type gate machinery on the 60= X 400= lock was in poor condition. Repair was not deemed practical, and complete replacement including sector gears and strut arms was required. Initially, replacement with a conventional electric-motor-driven, enclosed-gear-reduction, sector-gear type-system was considered. However, review of alternatives indicated individual, package-type, hydraulic units utilizing a direct-acting cylinder design would provide a more functional, cost-effective design. Whereas, replacement gear reduction machinery was estimated to cost over $1,000,000; the new hydraulic machinery was purchased by supply contract and installed by government hired labor at a cost of approximately $650,000.

New System Features

Individual hydraulic package units for each gate leaf consist of a small compact 25 hp, 15 gpm, variable-delivery, pressure-compensated pump system with a 50-gallon reservoir and associated control and relief valves.

Proportional-directional valves provide precise speed control, having acceleration and deceleration ramps to minimize machinery shock. The automatic two-speed miter gate control (with manual operator override capability) is accomplished via 120 vac inputs to the hydraulic 4-way valve controller setpoint cards which facilitates interface of the speed control in PLC mode and manual mode.

Direct-connected, 8-inch bore hydraulic cylinder assemblies having 5.5-inch diameter rods with a 146-inch maximum stroke operating at approximately 2400 psi maximum control the gates. The cylinder assemblies are equipped with a bellville-spring type shock assembly that reduces shock loads during operation. And, with a travel of 1-3/8 inches in both compression and extension, the shock provides flexibility for proper mitering of the gate leaves.

Combination counterbalance/load check valves are manifold-mounted on each cylinder and provide a dual function. Primarily, these valves hold the gate leafs in place when the hydraulic units are off, such as in the miter, recess, or any intermediate position. This eliminates the need for a supplemental gate recess latch system. Secondly, while operating, the valves also compensate for changing external loads on the gate leaf, such as wave action, assisting in the precise speed control achieved. The old system would often trip out due to wave action. The new system can handle large wave action without problems.

A more environmentally friendly hydraulic oil has been used, Mobil EAL 224. Overall system design is very compact, requiring only a 50-gallon reservoir and a cylinder that holds 30 gallons maximum. A closed breather system to minimize moisture in the reservoir was included.

The machinery operation is normally controlled through the lock PLC system. However, a minimal hardwired backup control system has been provided in the unlikely event of failure of the PLC system. The backup manual operational controls are piggybacked on the benchboard pushbuttons used for normal PLC control.

Also, each individual hydraulic power unit has an on-board local control station that was beneficial during shop testing and especially during initial field startup and installation. The local stations have also proven beneficial for normal maintenance, readjustment, and testing.

A spare hydraulic unit was purchased. Should one of the installed units malfunction and require lengthy repairs, the spare unit could be set on the lock wall for temporary operation. A complete spare cylinder assembly was also purchased.

UPGRADES & MODERNIZATION OF MECHANICAL & ELECTRICAL SYSTEMS AT BARKLEY LOCK

HISTORY

Barkley Lock was constructed and placed in operation in the mid-sixties. The lock was a typical Corps design with centralized hydraulic pumps in the Operations Building. The pumps were tied to the hydraulic cylinders in each of the four gate machinery and four culvert valve machinery recesses via thousands of feet of piping and through a crowded cluster of manual 4-way control valves under each of the upper and lower control stands. The supporting electrical controls were standard hardwired, relay based systems.

1980's MECHANICAL AND ELECTRICAL EQUIPMENT MODIFICATIONS

In the early eighties, the obsolete manual 4-way directional control valves controlling the culvert valves were replaced with solenoid-controlled, 4-way valves which were located in the gallery near the respective cylinders. This helped reduce the piping clutter under control stands and eliminated some of the piping in the galleries. The obsolete miter gate manual, 4-way directional control valves were replaced with new manual, 4-way valves having throttling capability which provided much better operating control of the miter gates.

To accommodate the revised hydraulic equipment, the lock electrical control system was completely reworked. The control stand benchboards and control wiring were substantially modified using a centralized relay system.

FY 90 MECHANICAL & ELECTRICAL SYSTEMS UPGRADES

Due to age and obsolesce of the centralized hydraulic pumps and determination that there was severe deterioration of much of the hydraulic piping in the upper and lower crossover galleries, the lock hydraulic system was further modified. The work accomplished consisted of purchasing all equipment and materials by supply contract and installation by government personnel.

The revised system design utilized new unitized hydraulic power units to provide individual systems for the land and river wall machinery, allowing complete elimination of the existing crossover piping. New modular, manifold-mounted, proportional, directional valves and associated control valves were installed near their respective existing operating cylinders, reducing the overall piping required.

This revised hydraulic system design significantly reduced the overall system piping and oil required. The revised design eliminated 9,000 feet of the original 15,000 feet of 2-inch hydraulic pipe. Also, 2,100 gallons of the original 3300 gallons of oil in the pipes was eliminated. The revised design required only two 300-gallon pumping unit tanks, eliminating the existing 600-gallon operating tank and the 1000-gallon underground oil storage tank.

The revised hydraulic system design utilized variable delivery pumps and proportional directional control valves that provide for more automated and much better operational control of the miter gates and culvert valves, especially during high water. The design incorporated modular, subplate-mounted components to facilitate future maintenance and repairs. Extensive oil filtration was also provided to increase the equipment reliability and life.

The associated electrical control revision was PLC based, using the Square D Company=s SYMAX remote I/O system. The revised PLC based design allowed for elimination of over 8000 feet of 12/C, control cable. The new control system facilitates maintenance with its built-in self-diagnostics; solid state reliability, modular design and capability to trouble-shoot control malfunctions on-line.

The majority of the work at Barkley Lock was done in conjunction with a seven-week closure in which the lock was dewatered and major structural repairs were made to the miter gates. Four portable hydraulic power units were installed at each corner of the lock to provide temporary operation of the lock miter gates and culvert valves while the existing permanent hydraulic and electrical systems were being revised. Significant preplanning, technical direction and on-site coordination were required to accomplish this work simultaneously and in a very compressed time span.

FY 94 ADDITION OF FIBER OPTIC WIRING

Lightning strikes at Pickwick Locks in 1992 and Barkley Lock in 1993 damaged the PLC systems resulting lock outages and led to a revaluation of the PLC control systems design. In 1994, the Barkley PLC system was retrofitted with fiber optic wiring on the PLC communication links between the remote PLC racks. The equipment cost for the fiber optic cabling and interface modules was approximately $10,000. Installation by hired labor was $5,000.

A subsequent lightning strike at Barkley damaged the phone system; however, the PLC system was unaffected. The fiber optic wiring has also greatly reduced the number of nuisance trips where the PLC system power would have to be cycled to return to normal operation.

FY 96 ADDITION OF MINIMAL HARDWIRED BACKUP SYSTEM

During the FY 96 dewatering, the electrical control system was revised to provide a minimal, hardwired system for control of critical lock operations should the PLC system fail. New, compact, control panels were added in each operators stand for the hardwired system. Maintained selector switches were used to minimize wiring and relays. To be more user friendly, the selector switches were laid out on the panels similar to what the actual lock machinery is laid out. The PLC control software was revised to incorporate the hardwired system changes.

In the PLC mode, the miter gates have two speeds, automatically controlled by PLC position indicators to change speed. However, the operator can switch to slow speed on either gate leaf, overriding the PLC automatic control. Also, in the PLC mode, time delays, actuated by the end-of-travel limit switches, allow the system to bypass for approximately 3 seconds before automatically shutting off, achieving full bypass pressure. This assures full travel and allows wave action to settle out.

In the manual mode, controlled by the maintained selector switches, the operator runs the machinery to full open or close until the hydraulic system bypasses and then simply turns off the switches. Having no end-of-travel limits simplifies the manual system. Also, the operator can selectively control the fast and slow speeds of the individual gate leafs.

To facilitate hardwiring of the gate machinery controls, the existing miter gate 4-way directional control valves were replaced with a new Digivalve type 4-way valve that has on-board electronics for controlling ramping and speed control. The valves are capable of two adjustable speeds in each direction, actuated by discrete 120 vac inputs. This greatly simplified the interface design of the manual hardwired and PLC control system.

The existing PLC program was modified to accommodate the hardwired back-up system. The existing benchboard controls were modified to accommodate the revised system.

The supplemental electrically controlled, air operated gate recess latch system had been unreliable and did not function much of the time. As an alternative, counterbalance valves had been added during the hydraulic system revision in 1990. The counterbalance valves have proved much more reliable holding the gates in the recess. Therefore, the recess latch system was removed along with its ladder logic in the PLC program.

CONCLUSION

Advances in industrial hydraulic equipment have led to more cost-effective lock operating systems. System design is moving away from large, low pressure, centralized systems to small, high pressure, unitized systems. These systems require much less piping and hydraulic oil. Application of direct-acting cylinder design for miter gates is on-going in several districts throughout the Corps.

With the advent of programmable logic controller (PLC) technology for industrial electrical controls, advances in electrical controls have been even more dramatic. The Nashville District installed its first PLC system in 1984 and now has five locks considered fully PLCed. The other 13 district locks all have PLC systems to a lesser extent for dedicated systems such as water level indication. There have been several *lessons learned* in the application of this new technology. Providing the proper mix of PLC and minimal hardwired backup, and use of fiber optics technology for greater system reliability and lightning protection are two critical areas to address.

Another, often overlooked, means to achieve an overall cost effective system is to choose mechanical and electrical components that complement each other. For example, proper selection of mechanical equipment can greatly simplify the electrical engineer=s design requirements.

Major benefits, both during installation and long term, can be obtained installing the PLC systems with in-house personnel. The majority of Nashville District PLC systems have been installed during scheduled dewaterings or short closures by government maintenance unit personnel supplemented by project electricians from several of the locks. The maintenance unit and project electricians are already familiar with the existing hardwired systems the PLC system replaces. Participating in the installation of the PLC system gives the in-house personnel hands-on knowledge of the new PLC system equipment, which is invaluable in performing future maintenance, troubleshooting and repairs.

Finally, the best way to ensure a successful application is to directly involve and obtain input from inception to completion from the maintenance personnel who install the equipment and the project personnel who must operate and maintain these new or revised mechanical and electrical systems.

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